

## **CUMBERLAND / PIEDMONT NETWORK**

### **ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE CUMBERLAND/PIEDMONT NETWORK**

**October 2004**

#### **Objective**

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

#### **Risk Assessment Methodology**

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

#### **Ozone-Sensitive Plant Species**

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop identified both sensitive and bioindicator species for ozone, and published its

determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

### **Levels of Ozone Exposure**

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone  $\geq 60$  ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations  $\geq 100$  ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The significance of the higher concentrations is also reflected in the requirement that there be

a specified minimum number of hours of exposure to concentrations  $\geq 100$  ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours  $\geq 100$  ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

### **Soil Moisture Status**

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to  $-4.0$ , a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

## Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

### **Literature Cited**

Heck, W.W. and E.B. Cowling. 1997. The Need for a Long-term Cumulative Secondary Ozone Standard - An Ecological Perspective. *Environmental Management*. January

Lefohn, AS, W Jackson, D. Shadwick, and HP Knudsen. 1997. Effect of surface ozone exposures on vegetation grown in the Southern Appalachian Mountains: identification of possible areas of concern. *Atmospheric Environment* 31(11):1695-1708.

U.S. National Park Service. 2003. Ozone Sensitive Plant Species on National Park Service and US Fish and Wildlife Service Lands. NPS D1522. Natural Resource Report NPS/NRARD/NRR-2003/01. Air Resources Division. Denver, CO. 21 pp. (Available at [www2.nature.nps.gov/ard/pubs/index.htm](http://www2.nature.nps.gov/ard/pubs/index.htm))

## SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE CUMBERLAND/PIEDMONT NETWORK

| Park                           | Code | State | Risk     | O3 Data   |
|--------------------------------|------|-------|----------|-----------|
| Abraham Lincoln Birthplace NHS | ABLI | KY    | moderate | kriged    |
| Carl Sandburg Home NHS         | CARL | NC    | moderate | kriged    |
| Chickamauga & Chattanooga NMP  | CHCH | GA    | high     | kriged    |
| Cowpens NB                     | COWP | SC    | high     | monitored |
| Cumberland Gap NHP             | CUGA | KY    | high     | kriged    |
| Fort Donelson NB               | FODO | TN    | high     | kriged    |
| Guilford Courthouse NMP        | GUCO | NC    | high     | kriged    |
| Kings Mountain NMP             | KIMO | SC    | high     | kriged    |
| Little River Canyon NPRES      | LIRI | AL    | high     | kriged    |
| Mammoth Cave NP                | MACA | KY    | high     | monitored |
| Ninety Six NHS                 | NISI | SC    | low      | kriged    |
| Russell Cave NM                | RUCA | AL    | moderate | kriged    |
| Shiloh NMP                     | SHIL | TN    | high     | kriged    |
| Stones River NB                | STRI | TN    | high     | kriged    |

A portion of the Natchez Trace National Scenic Trail passes through the network. A stand-alone assessment of risk has been produced for sites along the Natchez Trace Trail.

## ABRAHAM LINCOLN BIRTHPLACE NATIONAL HISTORIC SITE (ABLI)

### Plant Species Sensitive to Ozone

| <i>Latin Name</i>                  | <i>Common Name</i> | <i>Family</i>  |
|------------------------------------|--------------------|----------------|
| <i>Cercis canadensis</i>           | Redbud             | Fabaceae       |
| <i>Fraxinus americana</i>          | White ash          | Oleaceae       |
| <i>Liquidambar styraciflua</i>     | Sweetgum           | Hamamelidaceae |
| <i>Liriodendron tulipifera</i>     | Yellow-poplar      | Magnoliaceae   |
| <i>Parthenocissus quinquefolia</i> | Virginia creeper   | Vitaceae       |
| <i>Platanus occidentalis</i>       | American sycamore  | Platanaceae    |
| <i>Prunus serotina</i>             | Black cherry       | Rosaceae       |
| <i>Robinia pseudoacacia</i>        | Black locust       | Fabaceae       |
| <i>Sassafras albidum</i>           | Sassafras          | Lauraceae      |
| <i>Vitis labrusca</i>              | Northern fox grape | Vitaceae       |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

|                    |   |
|--------------------|---|
| Natural Ecosystems | 8 - 12 ppm-hr (foliar injury)                     |
| Tree Seedlings     | 10 - 16 ppm-hr (1-2% reduction in growth)         |
| Crops              | 15 - 20 ppm-hr (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

|                              | <u>W126</u> | <u>N100</u> |
|------------------------------|-------------|-------------|
| Highly Sensitive Species     | 5.9 ppm-hr  | 6           |
| Moderately Sensitive Species | 23.8 ppm-hr | 51          |
| Low Sensitivity              | 66.6 ppm-hr | 135         |

### Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours

above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for ABLI |      |      |      |      |      |
|---------------------------------|------|------|------|------|------|
|                                 | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06                           | 28   | 22   | 20   | 29   | 34   |
| W126                            | 37.0 | 29.0 | 28.3 | 46.7 | 58.1 |
| N60                             | 674  | 519  | 514  | 836  | 1049 |
| N80                             | 118  | 77   | 72   | 168  | 245  |
| N100                            | 16   | 7    | 9    | 24   | 19   |

### Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with  $\pm 0.9$  representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at ABLI |       |       |       |       |       |
|--|-------|-------|-------|-------|-------|
|  | 1995  | 1996  | 1997  | 1998  | 1999  |
| Month 1  | 0.28  | 1.29  | -2.99 | 0.19  | 1.06  |
| Month 2  | -1.38 | 1.76  | -0.28 | -2.05 | -3.13 |
| Month 3  | -0.71 | -0.84 | -0.97 | -2.56 | -3.05 |



Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at ABLI |       |       |       |       |       |
|---|-------|-------|-------|-------|-------|
|   | 1995  | 1996  | 1997  | 1998  | 1999  |
| April   | -0.17 | 1.99  | -1.38 | 3.52  | -0.94 |
| May   | 5.59  | 1.30  | 1.57  | -0.54 | -1.03 |
| June  | 0.28  | 1.29  | 4.08  | 4.83  | 1.06  |
| July  | -1.38 | 1.76  | -2.99 | 0.19  | -3.13 |
| August  | -0.71 | -0.84 | -0.28 | -2.05 | -3.05 |
| September   | -0.96 | 4.08  | -0.97 | -2.56 | -2.17 |
| October   | 3.29  | 0.65  | -1.02 | -0.59 | -0.57 |

### Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in three years. These levels of ozone can injure vegetation during high exposure years.
- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest Sum06 ozone exposure indices, 1998 and 1999, each had two months of moderate to severe drought. The year with a slightly lower ozone exposure, 1995, had one month of mild drought, while the two years with the lowest exposures experienced normal conditions and one month of moderate drought between them. Soil moisture levels associated with the W126 indices of exposure appear to be inversely related to ozone concentrations, although the pattern is not consistent. In the year with highest exposure, 1999, there were four months of mild to severe drought. The two mid-exposure years, 1998 and 1995, experienced two months of moderate and one month of mild drought, respectively. The second lowest year had normal soil moisture and the lowest year, 1997, experienced three months of mild and moderate drought.

The risk of foliar ozone injury to plants at Abraham Lincoln Birthplace National Historic Site is moderate. While the levels of ozone exposure consistently create the potential for

injury, dry soil conditions may reduce the likelihood of injury developing in years with the highest levels of exposure. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1995 and 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, American sycamore, black cherry and northern fox grape.

## CARL SANDBURG HOME NATIONAL HISTORIC SITE (CARL)

### Plant Species Sensitive to Ozone

| <i>Latin Name</i>                  | <i>Common Name</i>  | <i>Family</i>  |
|------------------------------------|---------------------|----------------|
| <i>Ailanthus altissima</i>         | Tree-of-heaven      | Simaroubaceae  |
| <i>Apocynum androsaemifolium</i>   | Spreading dogbane   | Apocynaceae    |
| <i>Asclepias exaltata</i>          | Tall milkweed       | Asclepiadaceae |
| <i>Asclepias syriaca</i>           | Common milkweed     | Asclepiadaceae |
| <i>Aster macrophyllus</i>          | Big-leaf aster      | Asteraceae     |
| <i>Fraxinus americana</i>          | White ash           | Oleaceae       |
| <i>Liriodendron tulipifera</i>     | Yellow-poplar       | Magnoliaceae   |
| <i>Parthenocissus quinquefolia</i> | Virginia creeper    | Vitaceae       |
| <i>Pinus rigida</i>                | Pitch pine          | Pinaceae       |
| <i>Pinus virginiana</i>            | Virginia pine       | Pinaceae       |
| <i>Platanus occidentalis</i>       | American sycamore   | Platanaceae    |
| <i>Prunus serotina</i>             | Black cherry        | Rosaceae       |
| <i>Robinia pseudoacacia</i>        | Black locust        | Fabaceae       |
| <i>Rudbeckia laciniata</i>         | Cut-leaf coneflower | Asteraceae     |
| <i>Sambucus canadensis</i>         | American elder      | Caprifoliaceae |
| <i>Sassafras albidum</i>           | Sassafras           | Lauraceae      |
| <i>Verbesina occidentalis</i>      | Crownbeard          | Asteraceae     |
| <i>Vitis labrusca</i>              | Northern fox grape  | Vitaceae       |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

|                    |   |
|--------------------|---|
| Natural Ecosystems | 8 - 12 ppm-hr (foliar injury)                     |
| Tree Seedlings     | 10 - 16 ppm-hr (1-2% reduction in growth)         |
| Crops              | 15 - 20 ppm-hr (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

|                              | <u>W126</u> | <u>N100</u> |
|------------------------------|-------------|-------------|
| Highly Sensitive Species     | 5.9 ppm-hr  | 6           |
| Moderately Sensitive Species | 23.8 ppm-hr | 51          |
| Low Sensitivity              | 66.6 ppm-hr | 135         |

### **Ozone Exposure Data**

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| <u>Ozone air quality data for CARL</u> |             |             |             |             |             |
|--|-------------|-------------|-------------|-------------|-------------|
|  | <u>1995</u> | <u>1996</u> | <u>1997</u> | <u>1998</u> | <u>1999</u> |
| Sum06                                  | 23          | 22          | 26          | 33          | 34          |
| W126                                   | 39.7        | 35.9        | 42.5        | 59.2        | 64.7        |
| N60                                    | 747         | 649         | 794         | 1078        | 1215        |
| N80                                    | 95          | 69          | 85          | 223         | 217         |
| N100                                   | 9           | 4           | 3           | 27          | 15          |

### **Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with  $\pm 0.9$  representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at CARL |       |       |       |       |       |
|--|-------|-------|-------|-------|-------|
|  | 1995  | 1996  | 1997  | 1998  | 1999  |
| Month 1  | 3.12  | -0.70 | -1.17 | -2.57 | 1.24  |
| Month 2  | -1.62 | 0.26  | -3.35 | -2.52 | -0.91 |
| Month 3  | 1.98  | -0.32 | 1.59  | -3.01 | -2.64 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at CARL |       |       |       |       |       |
|---|-------|-------|-------|-------|-------|
|   | 1995  | 1996  | 1997  | 1998  | 1999  |
| April   | -2.81 | -0.22 | 2.05  | 3.84  | -0.96 |
| May   | -0.22 | -0.70 | -0.13 | -1.65 | -0.39 |
| June  | 3.12  | 0.26  | 2.84  | 0.73  | 1.24  |
| July  | -1.62 | -0.32 | -1.17 | -2.57 | -0.91 |
| August  | 1.98  | 1.36  | -3.35 | -2.52 | -2.64 |
| September   | -0.16 | 2.86  | 1.59  | -3.01 | -1.75 |
| October   | 3.09  | -1.80 | 0.65  | -1.32 | -0.37 |

## Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in two years. The higher levels of exposure can injure vegetation.
- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The two years with the highest Sum06 values, 1999 and 1998, had one and three months of moderate to severe levels of drought, respectively. The mid-level exposure year, 1997, had two months of mild and severe drought. The two lowest exposure years, 1995 and 1996, had one month of mild drought and normal soil moisture, respectively. Relationships between the W126 index of exposure and soil

moisture also appear to be inverse, and are also inconsistent. Soil moisture levels associated with the highest exposure in 1999 showed two months of mild and moderate drought, while the second highest ozone year, 1998, had five months of mild to severe drought. The mid-exposure year 1997 had two months of mild and severe drought while the two lowest ozone years, 1995 and 1996, had two months of mild and moderate drought and normal soil moisture, respectively.

The risk of foliar ozone injury at the Carl Sandburg Home National Historic Site is moderate. The Sum06 threshold for injury is consistently satisfied, and the W126 index criteria are generally fulfilled. The N80 and N100 counts are high, but significantly lower in three years. The inverse relationship between ozone exposure and soil moisture is a significant factor affecting the potential for injury at the site. The years in which exposures exceed the injury thresholds are also ones in which there are two to five months of mild to severe drought. These moisture conditions constrain the uptake of ozone and reduce the likelihood that the exposures will produce foliar injury. One year, 1996, has favorable soil moisture conditions, but ozone exposures are lower. These conditions, however, suggest that levels of exposure capable of producing foliar injury may also occur at the site under conditions of minor drought, such as 1995, or normal soil moisture. The probability of foliar injury developing may greatest during years in which ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder, crownbeard and northern fox grape.

## CHICKAMAUGA AND CHATTANOOGA NATIONAL MILITARY PARK (CHCH)

### Plant Species Sensitive to Ozone

| <i>Latin Name</i>                  | <i>Common Name</i>   | <i>Family</i>  |
|------------------------------------|----------------------|----------------|
| <i>Ailanthus altissima</i>         | Tree-of-heaven       | Simaroubaceae  |
| <i>Asclepias syriaca</i>           | Common milkweed      | Asclepiadaceae |
| <i>Cercis canadensis</i>           | Redbud               | Fabaceae       |
| <i>Fraxinus americana</i>          | White ash            | Oleaceae       |
| <i>Fraxinus pennsylvanica</i>      | Green ash            | Oleaceae       |
| <i>Liquidambar styraciflua</i>     | Sweetgum             | Hamamelidaceae |
| <i>Liriodendron tulipifera</i>     | Yellow-poplar        | Magnoliaceae   |
| <i>Parthenocissus quinquefolia</i> | Virginia creeper     | Vitaceae       |
| <i>Pinus taeda</i>                 | Loblolly pine        | Pinaceae       |
| <i>Pinus virginiana</i>            | Virginia pine        | Pinaceae       |
| <i>Platanus occidentalis</i>       | American sycamore    | Platanaceae    |
| <i>Prunus serotina</i>             | Black cherry         | Rosaceae       |
| <i>Robinia pseudoacacia</i>        | Black locust         | Fabaceae       |
| <i>Rubus allegheniensis</i>        | Allegheny blackberry | Rosaceae       |
| <i>Rudbeckia laciniata</i>         | Cut-leaf coneflower  | Asteraceae     |
| <i>Sambucus canadensis</i>         | American elder       | Caprifoliaceae |
| <i>Sassafras albidum</i>           | Sassafras            | Lauraceae      |
| <i>Verbesina occidentalis</i>      | Crownbeard           | Asteraceae     |
| <i>Vitis labrusca</i>              | Northern fox grape   | Vitaceae       |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

|                    |   |
|--------------------|---|
| Natural Ecosystems | 8 - 12 ppm-hr (foliar injury)                     |
| Tree Seedlings     | 10 - 16 ppm-hr (1-2% reduction in growth)         |
| Crops              | 15 - 20 ppm-hr (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

|                              | <u>W126</u> | <u>N100</u> |
|------------------------------|-------------|-------------|
| Highly Sensitive Species     | 5.9 ppm-hr  | 6           |
| Moderately Sensitive Species | 23.8 ppm-hr | 51          |
| Low Sensitivity              | 66.6 ppm-hr | 135         |

### **Ozone Exposure Data**

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| <u>Ozone air quality data for CHCH</u> |             |             |             |             |             |
|--|-------------|-------------|-------------|-------------|-------------|
|  | <u>1995</u> | <u>1996</u> | <u>1997</u> | <u>1998</u> | <u>1999</u> |
| Sum06                                  | 19          | 22          | 23          | 27          | 27          |
| W126                                   | 33.6        | 36.0        | 35.6        | 53.5        | 52.8        |
| N60                                    | 598         | 655         | 626         | 894         | 933         |
| N80                                    | 103         | 108         | 109         | 244         | 219         |
| N100                                   | 18          | 12          | 8           | 51          | 31          |

### **Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with  $\pm 0.9$  representing normal soil moisture.



Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at CHCH |       |       |       |       |       |
|--|-------|-------|-------|-------|-------|
|  | 1995  | 1996  | 1997  | 1998  | 1999  |
| Month 1  | 0.00  | -1.78 | 0.34  | -1.00 | 0.88  |
| Month 2  | -1.57 | -0.26 | -0.88 | -1.27 | -2.13 |
| Month 3  | -0.82 | -0.92 | 3.13  | -3.01 | -1.99 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at CHCH |       |       |       |       |       |
|---|-------|-------|-------|-------|-------|
|   | 1995  | 1996  | 1997  | 1998  | 1999  |
| April   | -1.26 | 0.00  | 0.93  | 2.39  | -2.06 |
| May   | -1.09 | -1.78 | 0.86  | -1.50 | 0.49  |
| June  | 0.00  | -0.26 | 3.08  | 0.32  | 2.92  |
| July  | -1.57 | -0.92 | 0.34  | -1.00 | 0.88  |
| August  | -0.82 | 0.94  | -0.88 | -1.27 | -2.13 |
| September   | 0.97  | 2.01  | 3.13  | -3.01 | -1.99 |
| October   | 5.38  | -1.07 | 2.59  | -2.08 | 0.33  |

### Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated. The N100 values are highly variable and ranges from 8 to 51. The higher levels of exposure can injure vegetation
- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. Soil moisture levels during two years with the highest Sum06 values, 1998 and 1999, showed three and two months of moderate to severe drought, respectively. Two years with the lowest indices each had one month of mild drought, while in 1997, a

mid-exposure year, soil moisture was normal. Soil moisture levels associated with the W126 index also appear to be inversely related to ozone exposure, although the pattern is not consistent. In the highest ozone years, 1998 and 1999, soil moisture conditions were at moderate to severe drought levels for five and three months, respectively. In the two mid-exposure years, 1996 and 1997, there were two months of mild drought and normal moisture conditions, respectively. There were three months of mild drought in 1995, the year with the lowest exposure.

The risk of foliar ozone injury to plants at Chickamauga and Chattanooga National Military Park is high. The levels of ozone exposure consistently create the potential for injury, however dry soil conditions may reduce the likelihood of injury in a particular year. High levels of exposure capable of producing foliar injury also occur under conditions of minor drought and normal soil moisture. The probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder, crownbeard and northern fox grape.

## COWPENS NATIONAL BATTLEFIELD (COWP)

### Plant Species Sensitive to Ozone

| <i>Latin Name</i>                  | <i>Common Name</i>  | <i>Family</i>  |
|------------------------------------|---------------------|----------------|
| <i>Ailanthus altissima</i>         | Tree-of-heaven      | Simaroubaceae  |
| <i>Aster macrophyllus</i>          | Big-leaf aster      | Asteraceae     |
| <i>Cercis canadensis</i>           | Redbud              | Fabaceae       |
| <i>Fraxinus americana</i>          | White ash           | Oleaceae       |
| <i>Fraxinus pennsylvanica</i>      | Green ash           | Oleaceae       |
| <i>Liquidambar styraciflua</i>     | Sweetgum            | Hamamelidaceae |
| <i>Liriodendron tulipifera</i>     | Yellow-poplar       | Magnoliaceae   |
| <i>Parthenocissus quinquefolia</i> | Virginia creeper    | Vitaceae       |
| <i>Philadelphus coronarius</i>     | Sweet mock-orange   | Hydrangeaceae  |
| <i>Platanus occidentalis</i>       | American sycamore   | Platanaceae    |
| <i>Pinus taeda</i>                 | Loblolly pine       | Pinaceae       |
| <i>Pinus virginiana</i>            | Virginia pine       | Pinaceae       |
| <i>Prunus serotina</i>             | Black cherry        | Rosaceae       |
| <i>Rhus copallina</i>              | Flameleaf sumac     | Anacardiaceae  |
| <i>Robinia pseudoacacia</i>        | Black locust        | Fabaceae       |
| <i>Rudbeckia laciniata</i>         | Cut-leaf coneflower | Asteraceae     |
| <i>Sambucus canadensis</i>         | American elder      | Caprifoliaceae |
| <i>Sassafras albidum</i>           | Sassafras           | Lauraceae      |
| <i>Verbesina occidentalis</i>      | Crownbeard          | Asteraceae     |
| <i>Vitis labrusca</i>              | Northern fox grape  | Vitaceae       |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. The index is in cumulative ppm-hr.

|                    |   |
|--------------------|---|
| Natural Ecosystems | 8 - 12 ppm-hr (foliar injury)                     |
| Tree Seedlings     | 10 - 16 ppm-hr (1-2% reduction in growth)         |
| Crops              | 15 - 20 ppm-hr (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

|                              | <u>W126</u> | <u>N100</u> |
|------------------------------|-------------|-------------|
| Highly Sensitive Species     | 5.9 ppm-hr  | 6           |
| Moderately Sensitive Species | 23.8 ppm-hr | 51          |
| Low Sensitivity              | 66.6 ppm-hr | 135         |

### **Ozone Exposure Data**

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for COWP |      |      |      |      |      |
|---------------------------------|------|------|------|------|------|
|                                 | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06                           | 24   | 30   | 40   | 39   | 36   |
| W126                            | 33.1 | 33.7 | 54.6 | 55.4 | 51.4 |
| N60                             | 581  | 647  | 963  | 942  | 913  |
| N80                             | 112  | 72   | 199  | 236  | 171  |
| N100                            | 11   | 2    | 8    | 30   | 17   |

### **Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil

moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with  $\pm 0.9$  representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at COWP |       |       |      |       |       |
|--|-------|-------|------|-------|-------|
|  | 1995  | 1996  | 1997 | 1998  | 1999  |
| Month 1  | 2.99  | 0.27  | 0.56 | -0.35 | 0.81  |
| Month 2  | -1.49 | -1.13 | 1.14 | -2.35 | -1.78 |
| Month 3  | 6.28  | -1.04 | 1.34 | -1.05 | -2.36 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at COWP |       |       |       |       |       |
|---|-------|-------|-------|-------|-------|
|   | 1995  | 1996  | 1997  | 1998  | 1999  |
| April   | -2.28 | 0.40  | 1.64  | 5.34  | -0.13 |
| May   | -1.05 | 0.27  | 0.07  | -0.90 | -1.54 |
| June  | 2.99  | -1.13 | 1.43  | -0.35 | 0.81  |
| July  | -1.49 | -1.04 | 1.12  | -2.35 | -1.78 |
| August  | 6.28  | 0.64  | -2.38 | -1.05 | -2.36 |
| September   | 0.42  | 1.78  | 0.56  | -0.13 | -0.49 |
| October   | 2.61  | -0.65 | 1.14  | -0.96 | 1.53  |

## Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value is significantly greater than the threshold and the N100 count exceeded its threshold value in four of five years, thus the criteria for injury under the W126 index are satisfied. Both the Sum06 and W126 indices exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and demonstrate that there are a significant numbers of hours during which plants are exposed to potentially harmful levels of ozone.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. During the highest Sum06 exposure in 1997, soil moisture was normal. In each of three other years, 1996, 1998 and 1999, there were two months of mild and moderate drought, and there was one month of mild drought in 1995, the lowest exposure year. There also does not appear to be any association between the W126 index of exposure and soil moisture. Four of the five years had two or three months of mild and moderate drought with one month of moderate drought in the remaining year 1997.

The risk of foliar ozone injury to plants at Cowpens National Battlefield is high. Both the Sum06 and W126 exposure thresholds are satisfied. The number of hours of exposure to 80 ppb and 100 ppb is generally high, but variable. Levels of ozone exposure and soil moisture are not related and moisture conditions fostering or constraining the uptake of ozone can occur at any exposure. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1997 and 1998 when ozone levels exceed the thresholds, and soil moisture levels are under comparatively short-term drought.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder, crownbeard, and northern fox grape.

## CUMBERLAND GAP NATIONAL HISTORICAL PARK (CUGA)

### Plant Species Sensitive to Ozone

| <i>Latin Name</i>                  | <i>Common Name</i>   | <i>Family</i>  |
|------------------------------------|----------------------|----------------|
| <i>Ailanthus altissima</i>         | Tree-of-heaven       | Simaroubaceae  |
| <i>Asclepias exaltata</i>          | Tall milkweed        | Asclepiadaceae |
| <i>Asclepias syriaca</i>           | Common milkweed      | Asclepiadaceae |
| <i>Aster acuminatus</i>            | Whorled aster        | Asteraceae     |
| <i>Aster umbellatus</i>            | Flat-topped aster    | Asteraceae     |
| <i>Cercis canadensis</i>           | Redbud               | Fabaceae       |
| <i>Fraxinus americana</i>          | White ash            | Oleaceae       |
| <i>Fraxinus pennsylvanica</i>      | Green ash            | Oleaceae       |
| <i>Liquidambar styraciflua</i>     | Sweetgum             | Hamamelidaceae |
| <i>Liriodendron tulipifera</i>     | Yellow-poplar        | Magnoliaceae   |
| <i>Parthenocissus quinquefolia</i> | Virginia creeper     | Vitaceae       |
| <i>Pinus rigida</i>                | Pitch pine           | Pinaceae       |
| <i>Pinus virginiana</i>            | Virginia pine        | Pinaceae       |
| <i>Platanus occidentalis</i>       | American sycamore    | Platanaceae    |
| <i>Prunus serotina</i>             | Black cherry         | Rosaceae       |
| <i>Robinia pseudoacacia</i>        | Black locust         | Fabaceae       |
| <i>Rubus allegheniensis</i>        | Allegheny blackberry | Rosaceae       |
| <i>Rudbeckia laciniata</i>         | Cut-leaf coneflower  | Asteraceae     |
| <i>Sambucus canadensis</i>         | American elder       | Caprifoliaceae |
| <i>Sassafras albidum</i>           | Sassafras            | Lauraceae      |
| <i>Verbesina occidentalis</i>      | Crownbeard           | Asteraceae     |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

|                    |   |
|--------------------|---|
| Natural Ecosystems | 8 - 12 ppm-hr (foliar injury)                     |
| Tree Seedlings     | 10 - 16 ppm-hr (1-2% reduction in growth)         |
| Crops              | 15 - 20 ppm-hr (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

|                              | <u>W126</u> | <u>N100</u> |
|------------------------------|-------------|-------------|
| Highly Sensitive Species     | 5.9 ppm-hr  | 6           |
| Moderately Sensitive Species | 23.8 ppm-hr | 51          |
| Low Sensitivity              | 66.6 ppm-hr | 135         |

### **Ozone Exposure Data**

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| <u>Ozone air quality data for CUGA</u> |             |             |             |             |             |
|--|-------------|-------------|-------------|-------------|-------------|
|  | <u>1995</u> | <u>1996</u> | <u>1997</u> | <u>1998</u> | <u>1999</u> |
| Sum06                                  | 22          | 17          | 23          | 27          | 27          |
| W126                                   | 37.6        | 33.3        | 35.3        | 48.6        | 49.5        |
| N60                                    | 682         | 595         | 627         | 842         | 903         |
| N80                                    | 117         | 104         | 105         | 200         | 184         |
| N100                                   | 15          | 9           | 9           | 38          | 20          |

### **Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with  $\pm 0.9$  representing normal soil moisture.



Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at CUGA |       |      |       |       |       |
|--|-------|------|-------|-------|-------|
|  | 1995  | 1996 | 1997  | 1998  | 1999  |
| Month 1  | 0.54  | 2.73 | -1.33 | -0.54 | -0.84 |
| Month 2  | -2.95 | 1.04 | 0.35  | -1.49 | -3.26 |
| Month 3  | -1.97 | 2.03 | -0.03 | -2.85 | -1.42 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at CUGA |       |      |       |       |       |
|---|-------|------|-------|-------|-------|
|   | 1995  | 1996 | 1997  | 1998  | 1999  |
| April   | -0.39 | 1.39 | -1.65 | 5.46  | -0.97 |
| May   | 4.43  | 2.73 | 1.41  | 1.07  | -1.87 |
| June  | 0.54  | 1.04 | 4.17  | 4.96  | -0.84 |
| July  | -2.95 | 2.03 | -1.33 | -0.54 | -3.26 |
| August  | -1.97 | 0.46 | 0.35  | -1.49 | -1.42 |
| September   | 0.29  | 3.08 | -0.03 | -2.85 | -2.31 |
| October   | 1.85  | 1.33 | -0.83 | -1.62 | -0.23 |

### **Risk Analysis**

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in some years. These levels of exposure can injure vegetation.
- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. Soil moisture in the two years with the highest Sum06 values, 1998 and 1999, showed two months of mild to severe drought each year. The two mid-exposure years, 1997 and 1995, experienced one and two months of mild and moderate drought,

respectively. The lowest exposure year, 1996, had normal soil moisture conditions. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure. When ozone exposures were highest in 1999 and 1998, there were four and three months of mild to severe drought, respectively. The remaining three years had lower and similar levels of exposure. Two years had two months of mild and moderate drought each, and the lowest exposure year, 1996, had normal levels of soil moisture.

The risk of foliar ozone injury to plants at Cumberland Gap National Historical Park is high. The levels of ozone exposure consistently create the potential for injury, however dry soil conditions may reduce the likelihood of injury in the highest exposure years. High levels of exposure capable of producing foliar injury also occur under conditions of minor drought and normal soil moisture. The probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, tall milkweed, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder and crownbeard.

## FORT DONELSON NATIONAL BATTLEFIELD (FODO)

### Plant Species Sensitive to Ozone

| <i>Latin Name</i>                  | <i>Common Name</i> | <i>Family</i>  |
|------------------------------------|--------------------|----------------|
| <i>Ailanthus altissima</i>         | Tree-of-heaven     | Simaroubaceae  |
| <i>Asclepias syriaca</i>           | Common milkweed    | Asclepiadaceae |
| <i>Cercis canadensis</i>           | Redbud             | Fabaceae       |
| <i>Fraxinus americana</i>          | White ash          | Oleaceae       |
| <i>Fraxinus pennsylvanica</i>      | Green ash          | Oleaceae       |
| <i>Liquidambar styraciflua</i>     | Sweetgum           | Hamamelidaceae |
| <i>Liriodendron tulipifera</i>     | Yellow-poplar      | Magnoliaceae   |
| <i>Parthenocissus quinquefolia</i> | Virginia creeper   | Vitaceae       |
| <i>Pinus taeda</i>                 | Loblolly pine      | Pinaceae       |
| <i>Pinus virginiana</i>            | Virginia pine      | Pinaceae       |
| <i>Platanus occidentalis</i>       | American sycamore  | Platanaceae    |
| <i>Prunus serotina</i>             | Black cherry       | Rosaceae       |
| <i>Robinia pseudoacacia</i>        | Black locust       | Fabaceae       |
| <i>Sambucus canadensis</i>         | American elder     | Caprifoliaceae |
| <i>Sassafras albidum</i>           | Sassafras          | Lauraceae      |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

|                    |   |
|--------------------|---|
| Natural Ecosystems | 8 - 12 ppm-hr (foliar injury)                     |
| Tree Seedlings     | 10 - 16 ppm-hr (1-2% reduction in growth)         |
| Crops              | 15 - 20 ppm-hr (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

|                              | <u>W126</u> | <u>N100</u> |
|------------------------------|-------------|-------------|
| Highly Sensitive Species     | 5.9 ppm-hr  | 6           |
| Moderately Sensitive Species | 23.8 ppm-hr | 51          |
| Low Sensitivity              | 66.6 ppm-hr | 135         |

## Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for FODO |      |      |      |      |      |
|---------------------------------|------|------|------|------|------|
|                                 | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06                           | 12   | 16   | 16   | 15   | 25   |
| W126                            | 39.3 | 31.4 | 32.6 | 48.9 | 63.7 |
| N60                             | 710  | 556  | 581  | 884  | 1145 |
| N80                             | 106  | 60   | 83   | 153  | 249  |
| N100                            | 9    | 4    | 8    | 17   | 32   |

## Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with  $\pm 0.9$  representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at FODO |       |       |       |       |       |
|--|-------|-------|-------|-------|-------|
|  | 1995  | 1996  | 1997  | 1998  | 1999  |
| Month 1  | 0.33  | 0.49  | -1.50 | 3.31  | -1.23 |
| Month 2  | -2.06 | 3.03  | 0.61  | -0.93 | -2.01 |
| Month 3  | -0.95 | -0.02 | 1.74  | -2.50 | -1.97 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at FODO |       |       |       |       |       |
|---|-------|-------|-------|-------|-------|
|   | 1995  | 1996  | 1997  | 1998  | 1999  |
| April   | -0.25 | 0.80  | -0.80 | 3.42  | -1.35 |
| May   | 2.39  | 0.31  | 1.51  | 0.15  | -0.35 |
| June  | 0.98  | 0.49  | 4.61  | 5.86  | 1.61  |
| July  | 0.14  | 3.03  | -1.50 | 3.31  | -1.23 |
| August  | 0.59  | -0.02 | 0.61  | -0.93 | -2.01 |
| September   | 0.96  | 4.20  | 1.74  | -2.50 | -1.97 |
| October   | 2.81  | 1.09  | 0.43  | -0.88 | -0.87 |

### Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in two years. The higher levels of exposure can injure vegetation.
- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. Soil moisture in the year with the highest index, 1999, showed three months of mild and moderate drought. The three mid-exposure years had lower and similar Sum06 indices; two years had one month of mild or moderate drought and one year had conditions favorable for ozone uptake. The lowest ozone year, 1995, had one month of moderate drought. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure. In the highest ozone year, 1999, soil moisture conditions were at mild to moderate drought levels for four months, while the second highest year, 1998, had one month of moderate drought. The three lower exposure years had one month of mild drought among them.

The risk of foliar ozone injury to plants at Fort Donelson National Battlefield is high. The levels of ozone exposure are variable, but create the potential for injury in most years. However, dry soil conditions may reduce the likelihood of injury in the highest exposure years. Levels of ozone capable of producing foliar injury also occur under conditions of

minor drought and normal soil moisture. The probability of foliar injury developing may be greatest during years such as 1995, 1997 and 1998 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under short-term drought conditions that do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry and American elder.

## **GUILFORD COURTHOUSE NATIONAL MILITARY PARK (GUCO)**

### **Plant Species Sensitive to Ozone**

| <i>Latin Name</i>                  | <i>Common Name</i>  | <i>Family</i>  |
|------------------------------------|---------------------|----------------|
| <i>Ailanthus altissima</i>         | Tree-of-heaven      | Simaroubaceae  |
| <i>Asclepias syriaca</i>           | Common milkweed     | Asclepiadaceae |
| <i>Cercis canadensis</i>           | Redbud              | Fabaceae       |
| <i>Fraxinus americana</i>          | White ash           | Oleaceae       |
| <i>Fraxinus pennsylvanica</i>      | Green ash           | Oleaceae       |
| <i>Liquidambar styraciflua</i>     | Sweetgum            | Hamamelidaceae |
| <i>Liriodendron tulipifera</i>     | Yellow-poplar       | Magnoliaceae   |
| <i>Parthenocissus quinquefolia</i> | Virginia creeper    | Vitaceae       |
| <i>Pinus rigida</i>                | Pitch pine          | Pinaceae       |
| <i>Pinus taeda</i>                 | Loblolly pine       | Pinaceae       |
| <i>Pinus virginiana</i>            | Virginia pine       | Pinaceae       |
| <i>Platanus occidentalis</i>       | American sycamore   | Platanaceae    |
| <i>Prunus serotina</i>             | Black cherry        | Rosaceae       |
| <i>Rhus copallina</i>              | Flameleaf sumac     | Anacardiaceae  |
| <i>Robinia pseudoacacia</i>        | Black locust        | Fabaceae       |
| <i>Rudbeckia laciniata</i>         | Cut-leaf coneflower | Asteraceae     |
| <i>Sassafras albidum</i>           | Sassafras           | Lauraceae      |
| <i>Verbesina occidentalis</i>      | Crownbeard          | Asteraceae     |
| <i>Vitis labrusca</i>              | Northern fox grape  | Vitaceae       |

### **Representative Ozone Injury Thresholds**

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

|                    |   |
|--------------------|---|
| Natural Ecosystems | 8 - 12 ppm-hr (foliar injury)                     |
| Tree Seedlings     | 10 - 16 ppm-hr (1-2% reduction in growth)         |
| Crops              | 15 - 20 ppm-hr (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

|                              | <u>W126</u> | <u>N100</u> |
|------------------------------|-------------|-------------|
| Highly Sensitive Species     | 5.9 ppm-hr  | 6           |
| Moderately Sensitive Species | 23.8 ppm-hr | 51          |
| Low Sensitivity              | 66.6 ppm-hr | 135         |

### **Ozone Exposure Data**

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| <u>Ozone air quality data for GUCO</u> |             |             |             |             |             |
|--|-------------|-------------|-------------|-------------|-------------|
|  | <u>1995</u> | <u>1996</u> | <u>1997</u> | <u>1998</u> | <u>1999</u> |
| Sum06                                  | 22          | 27          | 31          | 32          | 29          |
| W126                                   | 31.9        | 36.5        | 46.5        | 54.1        | 42.5        |
| N60                                    | 581         | 663         | 826         | 929         | 736         |
| N80                                    | 86          | 99          | 161         | 232         | 166         |
| N100                                   | 9           | 10          | 12          | 32          | 24          |

### **Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with  $\pm 0.9$  representing normal soil moisture.



Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at GUCO |       |       |       |       |       |
|--|-------|-------|-------|-------|-------|
|  | 1995  | 1996  | 1997  | 1998  | 1999  |
| Month 1  | 6.39  | 0.82  | 0.50  | -1.83 | -1.05 |
| Month 2  | -0.69 | -0.78 | -0.72 | -1.68 | -1.19 |
| Month 3  | -0.12 | -0.29 | -2.21 | -1.58 | -0.86 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at GUCO |       |       |       |       |       |
|---|-------|-------|-------|-------|-------|
|   | 1995  | 1996  | 1997  | 1998  | 1999  |
| April   | -2.96 | 0.57  | 3.47  | 1.37  | 1.13  |
| May   | -0.11 | 0.82  | -1.76 | 0.24  | -1.54 |
| June  | 6.39  | -0.78 | 0.50  | -1.11 | -1.05 |
| July  | -0.69 | -0.29 | -0.72 | -1.83 | -1.19 |
| August  | -0.12 | 1.36  | -2.21 | -1.68 | -0.86 |
| September   | -1.21 | 6.90  | 0.02  | -1.58 | 9.76  |
| October   | 3.91  | 1.31  | -0.49 | -2.37 | 0.69  |

## Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours most years. These levels of exposure can injure vegetation.
- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest Sum06 ozone exposure value, 1998, had three months of mild drought. The next two highest years, 1997 and 1999, had one and two months of moderate and mild drought, respectively. The two years with the lowest exposures experienced normal conditions. Soil moisture levels associated with

the W126 index also appear inversely related to ozone exposure, although the relationship is not consistent. In the highest ozone year, 1998, soil moisture conditions were at mild to moderate drought levels for five months. In two years with mid-level exposure, 1997 and 1999, soil moisture conditions exhibited two and three months of drought respectively. The year with the lowest ozone, 1995, had two months of drought, while the second lowest year, 1996, had normal conditions.

The risk of foliar ozone injury to plants at Guilford Courthouse National Military Park is high. The levels of ozone exposure consistently create the potential for injury, however dry soil conditions may reduce the likelihood of injury in a high exposure year. Levels of exposure capable of producing foliar injury also occur under conditions of minor drought and normal soil moisture. The probability of foliar injury developing may be greatest during years such as 1995 and 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under short-term drought conditions that do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, crownbeard and northern fox grape.

## KINGS MOUNTAIN NATIONAL MILITARY PARK (KIMO)

### Plant Species Sensitive to Ozone

| <i>Latin Name</i>                  | <i>Common Name</i>  | <i>Family</i>  |
|------------------------------------|---------------------|----------------|
| <i>Ailanthus altissima</i>         | Tree-of-heaven      | Simaroubaceae  |
| <i>Cercis canadensis</i>           | Redbud              | Fabaceae       |
| <i>Fraxinus americana</i>          | White ash           | Oleaceae       |
| <i>Fraxinus pennsylvanica</i>      | Green ash           | Oleaceae       |
| <i>Liquidambar styraciflua</i>     | Sweetgum            | Hamamelidaceae |
| <i>Liriodendron tulipifera</i>     | Yellow-poplar       | Magnoliaceae   |
| <i>Parthenocissus quinquefolia</i> | Virginia creeper    | Vitaceae       |
| <i>Pinus taeda</i>                 | Loblolly pine       | Pinaceae       |
| <i>Pinus virginiana</i>            | Virginia pine       | Pinaceae       |
| <i>Platanus occidentalis</i>       | American sycamore   | Platanaceae    |
| <i>Prunus serotina</i>             | Black cherry        | Rosaceae       |
| <i>Rhus copallina</i>              | Flameleaf sumac     | Anacardiaceae  |
| <i>Robinia pseudoacacia</i>        | Black locust        | Fabaceae       |
| <i>Rudbeckia laciniata</i>         | Cut-leaf coneflower | Asteraceae     |
| <i>Sambucus canadensis</i>         | American elder      | Caprifoliaceae |
| <i>Sassafras albidum</i>           | Sassafras           | Lauraceae      |
| <i>Verbesina occidentalis</i>      | Crownbeard          | Asteraceae     |
| <i>Vitis labrusca</i>              | Northern fox grape  | Vitaceae       |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

|                    |   |
|--------------------|---|
| Natural Ecosystems | 8 - 12 ppm-hr (foliar injury)                     |
| Tree Seedlings     | 10 - 16 ppm-hr (1-2% reduction in growth)         |
| Crops              | 15 - 20 ppm-hr (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

|                              | <u>W126</u> | <u>N100</u> |
|------------------------------|-------------|-------------|
| Highly Sensitive Species     | 5.9 ppm-hr  | 6           |
| Moderately Sensitive Species | 23.8 ppm-hr | 51          |
| Low Sensitivity              | 66.6 ppm-hr | 135         |

### **Ozone Exposure Data**

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| <u>Ozone air quality data for KIMO</u> |             |             |             |             |             |
|--|-------------|-------------|-------------|-------------|-------------|
|  | <u>1995</u> | <u>1996</u> | <u>1997</u> | <u>1998</u> | <u>1999</u> |
| Sum06                                  | 24          | 27          | 30          | 37          | 34          |
| W126                                   | 35.6        | 33.8        | 40.4        | 51.6        | 47.8        |
| N60                                    | 646         | 607         | 728         | 891         | 829         |
| N80                                    | 118         | 98          | 122         | 220         | 189         |
| N100                                   | 16          | 10          | 12          | 32          | 28          |

### **Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with  $\pm 0.9$  representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at KIMO |       |       |       |       |       |
|--|-------|-------|-------|-------|-------|
|  | 1995  | 1996  | 1997  | 1998  | 1999  |
| Month 1  | 2.99  | -1.13 | 1.12  | -0.35 | 0.81  |
| Month 2  | -1.49 | -1.04 | -2.38 | -2.35 | -1.78 |
| Month 3  | 6.28  | 0.64  | 0.56  | -1.05 | -2.36 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at KIMO |       |       |       |       |       |
|---|-------|-------|-------|-------|-------|
|   | 1995  | 1996  | 1997  | 1998  | 1999  |
| April   | -2.28 | 0.40  | 1.64  | 5.34  | -0.13 |
| May   | -1.05 | 0.27  | 0.07  | -0.90 | -1.54 |
| June  | 2.99  | -1.13 | 1.43  | -0.35 | 0.81  |
| July  | -1.49 | -1.04 | 1.12  | -2.35 | -1.78 |
| August  | 6.28  | 0.64  | -2.38 | -1.05 | -2.36 |
| September   | 0.42  | 1.78  | 0.56  | -0.13 | -0.49 |
| October   | 2.61  | -0.65 | 1.14  | -0.96 | 1.53  |

### Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. In the Sum06 assessment there were three years, 1998, 1999 and 1996, representing the highest, second highest and second lowest exposures, respectively, each of which experienced two months of mild and moderate drought. Years with mid-level and the lowest exposure, 1997 and 1995, each had one month of moderate or mild drought. There also does not appear to be any association between the W126 level of exposure and soil moisture. Four of the five years experienced two or

three months of mild to moderate drought, and only 1997 had one month of moderate drought.

The risk of foliar ozone injury to plants at Kings Mountain National Military Park is high. The levels of ozone exposure consistently create the potential for injury although dry conditions can reduce the uptake from one to several months in any particular year. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 and 1997 in which exposures exceed injury thresholds and there are few months of mild or moderate drought.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder, crownbeard and northern fox grape.

## LITTLE RIVER CANYON NATIONAL PRESERVE (LIRI)

### Plant Species Sensitive to Ozone

| <i>Latin Name</i>                  | <i>Common Name</i> | <i>Family</i>  |
|------------------------------------|--------------------|----------------|
| <i>Ailanthus altissima</i>         | Tree-of-heaven     | Simaroubaceae  |
| <i>Apocynum androsaemifolium</i>   | Spreading dogbane  | Apocynaceae    |
| <i>Aster acuminatus</i>            | Whorled aster      | Asteraceae     |
| <i>Cercis canadensis</i>           | Redbud             | Fabaceae       |
| <i>Fraxinus americana</i>          | White ash          | Oleaceae       |
| <i>Fraxinus pennsylvanica</i>      | Green ash          | Oleaceae       |
| <i>Liquidambar styraciflua</i>     | Sweetgum           | Hamamelidaceae |
| <i>Liriodendron tulipifera</i>     | Yellow-poplar      | Magnoliaceae   |
| <i>Parthenocissus quinquefolia</i> | Virginia creeper   | Vitaceae       |
| <i>Pinus taeda</i>                 | Loblolly pine      | Pinaceae       |
| <i>Pinus virginiana</i>            | Virginia pine      | Pinaceae       |
| <i>Platanus occidentalis</i>       | American sycamore  | Platanaceae    |
| <i>Prunus serotina</i>             | Black cherry       | Rosaceae       |
| <i>Robinia pseudoacacia</i>        | Black locust       | Fabaceae       |
| <i>Sambucus canadensis</i>         | American elder     | Caprifoliaceae |
| <i>Sassafras albidum</i>           | Sassafras          | Lauraceae      |
| <i>Verbesina occidentalis</i>      | Crownbeard         | Asteraceae     |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

|                    |   |
|--------------------|---|
| Natural Ecosystems | 8 - 12 ppm-hr (foliar injury)                     |
| Tree Seedlings     | 10 - 16 ppm-hr (1-2% reduction in growth)         |
| Crops              | 15 - 20 ppm-hr (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

|                              | <u>W126</u> | <u>N100</u> |
|------------------------------|-------------|-------------|
| Highly Sensitive Species     | 5.9 ppm-hr  | 6           |
| Moderately Sensitive Species | 23.8 ppm-hr | 51          |
| Low Sensitivity              | 66.6 ppm-hr | 135         |

### **Ozone Exposure Data**

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| <u>Ozone air quality data for LIRI</u> |             |             |             |             |             |
|--|-------------|-------------|-------------|-------------|-------------|
|  | <u>1995</u> | <u>1996</u> | <u>1997</u> | <u>1998</u> | <u>1999</u> |
| Sum06                                  | 22          | 25          | 19          | 32          | 35          |
| W126                                   | 39.2        | 35.9        | 33.2        | 60.9        | 64.3        |
| N60                                    | 710         | 645         | 588         | 1030        | 1095        |
| N80                                    | 124         | 107         | 92          | 273         | 299         |
| N100                                   | 22          | 13          | 7           | 49          | 43          |

### **Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with  $\pm 0.9$  representing normal soil moisture.



Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at LIRI |       |       |       |       |       |
|--|-------|-------|-------|-------|-------|
|  | 1995  | 1996  | 1997  | 1998  | 1999  |
| Month 1  | 0.38  | -1.24 | -0.72 | 0.21  | -3.29 |
| Month 2  | -1.23 | 2.63  | 1.77  | -2.97 | -2.34 |
| Month 3  | -1.24 | 0.43  | 2.98  | -2.44 | -0.36 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at LIRI |       |       |       |       |       |
|---|-------|-------|-------|-------|-------|
|   | 1995  | 1996  | 1997  | 1998  | 1999  |
| April   | -0.61 | -0.12 | 0.49  | 1.87  | -1.50 |
| May   | -1.01 | -1.20 | 3.02  | -1.50 | 0.56  |
| June  | 0.38  | -1.24 | 6.25  | -0.52 | 4.76  |
| July  | -1.23 | 2.63  | -0.54 | -0.69 | -1.00 |
| August  | -1.24 | 0.43  | -0.72 | 0.21  | -3.29 |
| September   | 1.12  | 2.88  | 1.77  | -2.97 | -2.34 |
| October   | 6.30  | -0.29 | 2.98  | -2.44 | -0.36 |

## Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value exceeds the threshold and the N100 count meets the threshold requirement each year. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant numbers of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. Soil moisture during the years with the highest Sum06 ozone values, 1999 and 1998, showed two months of moderate to severe drought each year. Years with mid-level exposures, 1996 and 1995, had one and two months of mild drought, and the year with the lowest exposure, 1997, had normal soil moisture conditions. Soil moisture levels associated with the seasonal W126

index also appear inversely related to ozone exposure. In the highest ozone years, 1999 and 1998, soil moisture conditions were at moderate to severe drought levels for four and three months, respectively. In the years with mid-level exposures, 1995 and 1996, there were three and two months of mild drought, respectively. The lowest exposure year 1997 had normal soil moisture conditions.

The risk of foliar ozone injury to plants at Little River Canyon National Preserve is high. While the levels of ozone exposure consistently create the potential for injury, dry soil conditions may reduce the likelihood of injury developing in the highest exposure years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, redbud, white ash, yellow-poplar, American sycamore, black cherry, American elder and crownbeard.

## MAMMOTH CAVE NATIONAL PARK (MACA)

### Plant Species Sensitive to Ozone

| <i>Latin Name</i>                  | <i>Common Name</i>  | <i>Family</i>  |
|------------------------------------|---------------------|----------------|
| <i>Ailanthus altissima</i>         | Tree-of-heaven      | Simaroubaceae  |
| <i>Asclepias exaltata</i>          | Tall milkweed       | Asclepiadaceae |
| <i>Asclepias syriaca</i>           | Common milkweed     | Asclepiadaceae |
| <i>Aster macrophyllus</i>          | Big-leaf aster      | Asteraceae     |
| <i>Aster umbellatus</i>            | Flat-topped aster   | Asteraceae     |
| <i>Cercis canadensis</i>           | Redbud              | Fabaceae       |
| <i>Fraxinus americana</i>          | White ash           | Oleaceae       |
| <i>Fraxinus pennsylvanica</i>      | Green ash           | Oleaceae       |
| <i>Liquidambar styraciflua</i>     | Sweetgum            | Hamamelidaceae |
| <i>Liriodendron tulipifera</i>     | Yellow-poplar       | Magnoliaceae   |
| <i>Parthenocissus quinquefolia</i> | Virginia creeper    | Vitaceae       |
| <i>Pinus taeda</i>                 | Loblolly pine       | Pinaceae       |
| <i>Pinus virginiana</i>            | Virginia pine       | Pinaceae       |
| <i>Platanus occidentalis</i>       | American sycamore   | Platanaceae    |
| <i>Prunus serotina</i>             | Black cherry        | Rosaceae       |
| <i>Rhus copallina</i>              | Flameleaf sumac     | Anacardiaceae  |
| <i>Robinia pseudoacacia</i>        | Black locust        | Fabaceae       |
| <i>Rudbeckia laciniata</i>         | Cut-leaf coneflower | Asteraceae     |
| <i>Sambucus canadensis</i>         | American elder      | Caprifoliaceae |
| <i>Sassafras albidum</i>           | Sassafras           | Lauraceae      |
| <i>Verbesina occidentalis</i>      | Crownbeard          | Asteraceae     |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. The index is in cumulative ppm-hr.

|                    |   |
|--------------------|---|
| Natural Ecosystems | 8 - 12 ppm-hr (foliar injury)                     |
| Tree Seedlings     | 10 - 16 ppm-hr (1-2% reduction in growth)         |
| Crops              | 15 - 20 ppm-hr (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

|                              | <u>W126</u> | <u>N100</u> |
|------------------------------|-------------|-------------|
| Highly Sensitive Species     | 5.9 ppm-hr  | 6           |
| Moderately Sensitive Species | 23.8 ppm-hr | 51          |
| Low Sensitivity              | 66.6 ppm-hr | 135         |

### **Ozone Exposure Data**

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| <u>Ozone air quality data for MACA</u> |             |             |             |             |             |
|--|-------------|-------------|-------------|-------------|-------------|
|  | <u>1995</u> | <u>1996</u> | <u>1997</u> | <u>1998</u> | <u>1999</u> |
| Sum06                                  | 29          | 27          | 11          | -           | -           |
| W126                                   | 34.5        | 33.5        | 30.6        | 60.6        | 80.8        |
| N60                                    | 673         | 631         | 567         | 1118        | 1493        |
| N80                                    | 63          | 75          | 79          | 198         | 328         |
| N100                                   | 14          | 4           | 10          | 23          | 26          |

### **Soil Moisture Status**

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with  $\pm 0.9$  representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at MACA |       |       |       |      |      |
|--|-------|-------|-------|------|------|
|  | 1995  | 1996  | 1997  | 1998 | 1999 |
| Month 1  | -1.38 | 1.29  | -1.38 | -    | -    |
| Month 2  | -0.71 | 1.76  | 1.57  | -    | -    |
| Month 3  | -0.96 | -0.84 | 4.08  | -    | -    |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at MACA |       |       |       |       |       |
|---|-------|-------|-------|-------|-------|
|   | 1995  | 1996  | 1997  | 1998  | 1999  |
| April   | -0.17 | 1.99  | -1.38 | 3.52  | -0.94 |
| May   | 5.59  | 1.30  | 1.57  | -0.54 | -1.03 |
| June  | 0.28  | 1.29  | 4.08  | 4.83  | 1.06  |
| July  | -1.38 | 1.76  | -2.99 | 0.19  | -3.13 |
| August  | -0.71 | -0.84 | -0.28 | -2.05 | -3.05 |
| September   | -0.96 | 4.08  | -0.97 | -2.56 | -2.17 |
| October   | 3.29  | 0.65  | -1.02 | -0.59 | -0.57 |

## Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. Both the Sum06 and W126 indices exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and demonstrate that there are a significant numbers of hours during which plants are exposed to potentially harmful levels of ozone.
- Only three years of data are available for the 90-day Sum06 exposure index limiting the ability to assess relationships between exposure levels and soil moisture. There were only two months of mild drought during the three years, and ozone uptake was generally fostered. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the relationship is inconsistent. This relationship reduces the uptake of ozone and the effectiveness of the seasonal

exposure in producing foliar injury. The two highest exposure years, 1999 and 1998, had four and two months of mild to severe drought, respectively. Two years with intermediate and similar levels of exposure had one month of drought and normal moisture conditions. The year with the lowest exposure, 1997, had three months of drought.

The risk of foliar ozone injury to plants at Mammoth Cave National Park is high. Threshold levels for both the Sum06 and W126 indices are satisfied and hours of exposure to 80 and 100 ppb are generally high. The levels of ozone exposure consistently create the potential for injury during years with both normal soil moisture and drought. Due to the inverse relationship between ozone and soil moisture levels, dry soil conditions constrain the uptake of ozone and reduce the likelihood of injury in higher exposure years. The probability of foliar injury developing may be greatest during years such as 1995 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, tall milkweed, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder and crownbeard.

## NINETY SIX NATIONAL HISTORIC SITE (NISI)

### Plant Species Sensitive to Ozone

| <i>Latin Name</i>                  | <i>Common Name</i>  | <i>Family</i>  |
|------------------------------------|---------------------|----------------|
| <i>Ailanthus altissima</i>         | Tree-of-heaven      | Simaroubaceae  |
| <i>Cercis canadensis</i>           | Redbud              | Fabaceae       |
| <i>Fraxinus pennsylvanica</i>      | Green ash           | Oleaceae       |
| <i>Liquidambar styraciflua</i>     | Sweetgum            | Hamamelidaceae |
| <i>Liriodendron tulipifera</i>     | Yellow-poplar       | Magnoliaceae   |
| <i>Parthenocissus quinquefolia</i> | Virginia creeper    | Vitaceae       |
| <i>Pinus taeda</i>                 | Loblolly pine       | Pinaceae       |
| <i>Platanus occidentalis</i>       | American sycamore   | Platanaceae    |
| <i>Rudbeckia laciniata</i>         | Cut-leaf coneflower | Asteraceae     |
| <i>Sassafras albidum</i>           | Sassafras           | Lauraceae      |
| <i>Verbesina occidentalis</i>      | Crownbeard          | Asteraceae     |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

|                    |   |
|--------------------|---|
| Natural Ecosystems | 8 - 12 ppm-hr (foliar injury)                     |
| Tree Seedlings     | 10 - 16 ppm-hr (1-2% reduction in growth)         |
| Crops              | 15 - 20 ppm-hr (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

|                              | <u>W126</u> | <u>N100</u> |
|------------------------------|-------------|-------------|
| Highly Sensitive Species     | 5.9 ppm-hr  | 6           |
| Moderately Sensitive Species | 23.8 ppm-hr | 51          |
| Low Sensitivity              | 66.6 ppm-hr | 135         |

## Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for NISI |      |      |      |      |      |
|---------------------------------|------|------|------|------|------|
|                                 | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06                           | 20   | 19   | 26   | 38   | 32   |
| W126                            | 25.9 | 23.6 | 31.7 | 50.7 | 43.4 |
| N60                             | 477  | 424  | 583  | 917  | 780  |
| N80                             | 59   | 40   | 77   | 195  | 155  |
| N100                            | 5    | 2    | 3    | 24   | 13   |

## Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with  $\pm 0.9$  representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at NISI |       |       |       |       |       |
|--|-------|-------|-------|-------|-------|
|  | 1995  | 1996  | 1997  | 1998  | 1999  |
| Month 1  | 2.82  | -0.79 | 1.59  | -0.05 | -0.41 |
| Month 2  | -0.74 | -1.08 | -1.81 | -1.76 | -2.25 |
| Month 3  | 4.32  | -1.27 | 1.46  | -1.77 | 0.14  |



Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at NISI |       |       |       |       |       |
|---|-------|-------|-------|-------|-------|
|   | 1995  | 1996  | 1997  | 1998  | 1999  |
| April   | -2.53 | 0.66  | 0.73  | 2.78  | -1.10 |
| May   | -1.27 | -0.79 | -0.37 | 1.03  | -0.96 |
| June  | 2.82  | -1.08 | 1.58  | -0.05 | 2.67  |
| July  | -0.74 | -1.27 | 1.59  | -1.76 | -0.41 |
| August  | 4.32  | 1.31  | -1.81 | -1.77 | -2.25 |
| September   | 1.83  | 0.81  | 1.46  | 1.57  | 0.14  |
| October   | 2.06  | 1.45  | 1.93  | -1.09 | -0.16 |

### Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years although concentrations exceeded 100 ppb every year. The Sum06 threshold was satisfied each year and the W126 criteria in two of the five years.
- In two years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours at all three levels were significantly lower. In high exposure years, the levels of ozone could injure vegetation.
- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods do not appear to be related to the level of ozone exposure. Soil moisture levels in the two highest Sum06 ozone years, 1998 and 1999, showed two months of mild and one month of moderate drought, respectively. There was one month of mild drought in 1997 a mid-exposure year. The lowest exposure year, 1996, experienced two months of mild drought, and the second lowest year had normal soil moisture. Similarly, no relationships are apparent between the W126 index of exposure and soil moisture. Four of the five years experienced two or three months of mild to moderate drought, and only 1997, a mid-exposure year, had one month of mild drought.

The risk of foliar ozone injury at Ninety Six National Historical Site is low. The threshold level for injury is satisfied mainly by the Sum06 index, the W126 index is satisfied in two years, and N-values indicate that in some years there are frequent exposures to concentrations of ozone greater than 80 ppb and a several hours of exposure to 100 ppb. The levels of exposure vary significantly among the years. There is no

association between the level of ozone and soil moisture however there are two or more months of mild and moderate drought in most years that constrain the uptake of ozone and reduce the exposure.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, yellow-poplar, American sycamore, cut-leaf coneflower and crownbeard.

## RUSSELL CAVE NATIONAL MONUMENT (RUCA)

### Plant Species Sensitive to Ozone

| <i>Latin Name</i>                  | <i>Common Name</i> | <i>Family</i>  |
|------------------------------------|--------------------|----------------|
| <i>Ailanthus altissima</i>         | Tree-of-heaven     | Simaroubaceae  |
| <i>Cercis canadensis</i>           | Redbud             | Fabaceae       |
| <i>Fraxinus americana</i>          | White ash          | Oleaceae       |
| <i>Liquidambar styraciflua</i>     | Sweetgum           | Hamamelidaceae |
| <i>Liriodendron tulipifera</i>     | Yellow-poplar      | Magnoliaceae   |
| <i>Parthenocissus quinquefolia</i> | Virginia creeper   | Vitaceae       |
| <i>Pinus taeda</i>                 | Loblolly pine      | Pinaceae       |
| <i>Pinus virginiana</i>            | Virginia pine      | Pinaceae       |
| <i>Platanus occidentalis</i>       | American sycamore  | Platanaceae    |
| <i>Prunus serotina</i>             | Black cherry       | Rosaceae       |
| <i>Robinia pseudoacacia</i>        | Black locust       | Fabaceae       |
| <i>Sambucus canadensis</i>         | American elder     | Caprifoliaceae |
| <i>Sassafras albidum</i>           | Sassafras          | Lauraceae      |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

|                    |   |
|--------------------|---|
| Natural Ecosystems | 8 - 12 ppm-hr (foliar injury)                     |
| Tree Seedlings     | 10 - 16 ppm-hr (1-2% reduction in growth)         |
| Crops              | 15 - 20 ppm-hr (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

|                              | <u>W126</u> | <u>N100</u> |
|------------------------------|-------------|-------------|
| Highly Sensitive Species     | 5.9 ppm-hr  | 6           |
| Moderately Sensitive Species | 23.8 ppm-hr | 51          |
| Low Sensitivity              | 66.6 ppm-hr | 135         |

## Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for RUCA |      |      |      |      |      |
|---------------------------------|------|------|------|------|------|
|                                 | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06                           | 23   | 25   | 18   | 27   | 24   |
| W126                            | 33.2 | 37.0 | 34.7 | 51.3 | 55.4 |
| N60                             | 611  | 682  | 617  | 886  | 986  |
| N80                             | 82   | 98   | 100  | 205  | 223  |
| N100                            | 11   | 8    | 7    | 34   | 27   |

## Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with  $\pm 0.9$  representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at RUCA |       |       |       |       |       |
|--|-------|-------|-------|-------|-------|
|  | 1995  | 1996  | 1997  | 1998  | 1999  |
| Month 1  | 0.38  | -1.24 | -0.72 | 0.21  | -3.29 |
| Month 2  | -1.23 | 2.63  | 1.77  | -2.97 | -2.34 |
| Month 3  | -1.24 | 0.43  | 2.98  | -2.44 | -0.36 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at RUCA |       |       |       |       |       |
|---|-------|-------|-------|-------|-------|
|   | 1995  | 1996  | 1997  | 1998  | 1999  |
| April   | -0.61 | -0.12 | 0.49  | 1.87  | -1.50 |
| May   | -1.01 | -1.20 | 3.02  | -1.50 | 0.56  |
| June  | 0.38  | -1.24 | 6.25  | -0.52 | 4.76  |
| July  | -1.23 | 2.63  | -0.54 | -0.69 | -1.00 |
| August  | -1.24 | 0.43  | -0.72 | 0.21  | -3.29 |
| September   | 1.12  | 2.88  | 1.77  | -2.97 | -2.34 |
| October   | 6.30  | -0.29 | 2.98  | -2.44 | -0.36 |

### Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- In two years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours at all three levels were significantly lower. In high exposure years, the levels of ozone could injure vegetation.
- Relationships between the 90-day Sum06 accumulation period index of ozone exposure and soil moisture are difficult to assess because ozone exposure was high and similar in four of the five years. However, they appear to be inversely related: when ozone is high, soil moisture is low, although the pattern is not consistent. In the highest exposure year 1998 there were two months of moderate drought. In each of the three mid-level exposure years, 1996, 1999 and 1995, there were one or two years of drought, while in 1997, the year with the lowest exposure, soil moisture conditions were normal. Soil moisture levels associated with the W126 index also appear inversely related to exposure, although the pattern is again not consistent. In the two highest exposure years, 1999 and 1998, there were four and three months, respectively, of mild to severe drought. The mid-exposure year 1997 had two months of mild drought. The years 1995 and 1997 had the lowest levels of ozone and experienced three months of mild drought and normal moisture conditions, respectively. Overall, most years experienced two or three months of drought with moderate and severe drought occurring in the highest W126 exposure years.

The risk of foliar ozone injury to plants at Russell Cave National Monument is moderate. While the levels of ozone exposure generally create the potential for injury, dry soil conditions may significantly reduce the likelihood of injury in the highest exposure years. However, levels of exposure capable of producing foliar injury also occur under conditions of minor drought and normal soil moisture. The probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, yellow-poplar, American sycamore, black cherry and American elder.

## SHILOH NATIONAL MILITARY PARK (SHIL)

### Plant Species Sensitive to Ozone

| <i>Latin Name</i>                  | <i>Common Name</i> | <i>Family</i>  |
|------------------------------------|--------------------|----------------|
| <i>Cercis canadensis</i>           | Redbud             | Fabaceae       |
| <i>Fraxinus americana</i>          | White ash          | Oleaceae       |
| <i>Fraxinus pennsylvanica</i>      | Green ash          | Oleaceae       |
| <i>Liquidambar styraciflua</i>     | Sweetgum           | Hamamelidaceae |
| <i>Liriodendron tulipifera</i>     | Yellow-poplar      | Magnoliaceae   |
| <i>Parthenocissus quinquefolia</i> | Virginia creeper   | Vitaceae       |
| <i>Pinus taeda</i>                 | Loblolly pine      | Pinaceae       |
| <i>Pinus virginiana</i>            | Virginia pine      | Pinaceae       |
| <i>Platanus occidentalis</i>       | American sycamore  | Platanaceae    |
| <i>Prunus serotina</i>             | Black cherry       | Rosaceae       |
| <i>Robinia pseudoacacia</i>        | Black locust       | Fabaceae       |
| <i>Sambucus canadensis</i>         | American elder     | Caprifoliaceae |
| <i>Sassafras albidum</i>           | Sassafras          | Lauraceae      |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

|                    |   |
|--------------------|---|
| Natural Ecosystems | 8 - 12 ppm-hr (foliar injury)                     |
| Tree Seedlings     | 10 - 16 ppm-hr (1-2% reduction in growth)         |
| Crops              | 15 - 20 ppm-hr (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

|                              | <u>W126</u> | <u>N100</u> |
|------------------------------|-------------|-------------|
| Highly Sensitive Species     | 5.9 ppm-hr  | 6           |
| Moderately Sensitive Species | 23.8 ppm-hr | 51          |
| Low Sensitivity              | 66.6 ppm-hr | 135         |

## Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for SHIL |      |      |      |      |      |
|---------------------------------|------|------|------|------|------|
|                                 | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06                           | 15   | 28   | 24   | 31   | 43   |
| W126                            | 34.7 | 36   | 32.7 | 48.7 | 62   |
| N60                             | 621  | 648  | 603  | 884  | 1100 |
| N80                             | 95   | 81   | 69   | 158  | 261  |
| N100                            | 10   | 6    | 5    | 19   | 28   |

## Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with  $\pm 0.9$  representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at SHIL |       |       |       |       |       |
|--|-------|-------|-------|-------|-------|
|  | 1995  | 1996  | 1997  | 1998  | 1999  |
| Month 1  | -2.06 | 0.49  | -1.50 | -0.93 | -1.23 |
| Month 2  | -0.95 | 3.03  | 0.61  | -2.50 | -2.01 |
| Month 3  | -0.25 | -0.02 | 1.74  | -0.88 | -1.97 |



Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at SHIL |       |       |       |       |       |
|---|-------|-------|-------|-------|-------|
|   | 1995  | 1996  | 1997  | 1998  | 1999  |
| April   | -0.25 | 0.80  | -0.80 | 3.42  | -1.35 |
| May   | 2.39  | 0.31  | 1.51  | 0.15  | -0.35 |
| June  | 0.98  | 0.49  | 4.61  | 5.86  | 1.61  |
| July  | 0.14  | 3.03  | -1.50 | 3.31  | -1.23 |
| August  | 0.59  | -0.02 | 0.61  | -0.93 | -2.01 |
| September   | 0.96  | 4.20  | 1.74  | -2.50 | -1.97 |
| October   | 2.81  | 1.09  | 0.43  | -0.88 | -0.87 |

### Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in four of the years although concentrations exceeded 100 ppb every year. The Sum06 and the W126 criteria were satisfied in two the five years of data presented.
- In two years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours at all three levels were significantly lower. In high exposure years, the levels of ozone could injure vegetation.
- Relationships between the 90-day Sum06 accumulation periods and soil moisture are difficult to assess because of the limited number of months of drought. Soil moisture levels during the year with the highest exposure, 1999, show three months of mild to moderate drought. There were only three months of drought in the remaining four years and no associations between the Sum06 index of exposure and soil moisture were apparent. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In the highest ozone years, 1998 and 1999, soil moisture conditions were at mild and moderate drought levels for five and one month, respectively. In the remaining three years, soil moisture conditions were favorable for the uptake of ozone with only one month of mild drought in 1997, the lowest exposure year.

The risk of foliar ozone injury at Shiloh National Military Park is high. The Sum06 threshold for injury is consistently satisfied, and W126 threshold is satisfied

intermittently. The N-values indicate that exposures to 80 to 100 ppb vary considerably among years, and in some years exposure to 100 ppb is significant. In the highest exposure years, low soil moisture levels reduce the uptake of ozone, however exposure thresholds are also satisfied in years with more normal soil moisture conditions. It is anticipated that the risk of foliar injury developing may be greatest during years such as 1995, 1996 and 1998 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, American sycamore, black cherry and American elder.

## STONES RIVER NATIONAL BATTLEFIELD (STRI)

### Plant Species Sensitive to Ozone

| <i>Latin Name</i>                  | <i>Common Name</i> | <i>Family</i>  |
|------------------------------------|--------------------|----------------|
| <i>Ailanthus altissima</i>         | Tree-of-heaven     | Simaroubaceae  |
| <i>Asclepias syriaca</i>           | Common milkweed    | Asclepiadaceae |
| <i>Cercis canadensis</i>           | Redbud             | Fabaceae       |
| <i>Fraxinus americana</i>          | White ash          | Oleaceae       |
| <i>Fraxinus pennsylvanica</i>      | Green ash          | Oleaceae       |
| <i>Liquidambar styraciflua</i>     | Sweetgum           | Hamamelidaceae |
| <i>Parthenocissus quinquefolia</i> | Virginia creeper   | Vitaceae       |
| <i>Platanus occidentalis</i>       | American sycamore  | Platanaceae    |
| <i>Prunus serotina</i>             | Black cherry       | Rosaceae       |
| <i>Sambucus canadensis</i>         | American elder     | Caprifoliaceae |
| <i>Sassafras albidum</i>           | Sassafras          | Lauraceae      |

### Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

|                    |   |
|--------------------|---|
| Natural Ecosystems | 8 - 12 ppm-hr (foliar injury)                     |
| Tree Seedlings     | 10 - 16 ppm-hr (1-2% reduction in growth)         |
| Crops              | 15 - 20 ppm-hr (10% reduction in 25-35% of crops) |

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

|                              | <u>W126</u> | <u>N100</u> |
|------------------------------|-------------|-------------|
| Highly Sensitive Species     | 5.9 ppm-hr  | 6           |
| Moderately Sensitive Species | 23.8 ppm-hr | 51          |
| Low Sensitivity              | 66.6 ppm-hr | 135         |

## Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

| Ozone air quality data for STRI |      |      |      |      |      |
|---------------------------------|------|------|------|------|------|
|                                 | 1995 | 1996 | 1997 | 1998 | 1999 |
| Sum06                           | 24   | 25   | 21   | 25   | 27   |
| W126                            | 31.9 | 34.8 | 36.7 | 41.0 | 54.2 |
| N60                             | 590  | 650  | 680  | 744  | 969  |
| N80                             | 92   | 101  | 118  | 128  | 211  |
| N100                            | 12   | 11   | 14   | 17   | 28   |

## Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with  $\pm 0.9$  representing normal soil moisture.

Soil moisture status for the Sum06 index period.

| Palmer Z Index data for 3-month Sum06 period at STRI |      |       |       |       |       |
|--|------|-------|-------|-------|-------|
|  | 1995 | 1996  | 1997  | 1998  | 1999  |
| Month 1  | 0.98 | 0.49  | -1.50 | 3.31  | 1.61  |
| Month 2  | 0.14 | 3.03  | 0.61  | -0.93 | -1.23 |
| Month 3  | 0.59 | -0.02 | 1.74  | -2.50 | -2.01 |

Soil moisture status for the April through October period for the W126 index.

| Palmer Z Index data for the 7-month W126 period at STRI |      |       |       |       |       |
|---|------|-------|-------|-------|-------|
|   | 1995 | 1996  | 1997  | 1998  | 1999  |
| April   | 0.25 | 0.80  | -0.80 | 3.42  | -1.35 |
| May   | 2.39 | 0.31  | 1.51  | 0.15  | -0.35 |
| June  | 0.98 | 0.49  | 4.61  | 5.86  | 1.61  |
| July  | 0.14 | 3.03  | -1.50 | 3.31  | -1.23 |
| August  | 0.59 | -0.02 | 0.61  | -0.93 | -2.01 |
| September   | 0.96 | 4.20  | 1.74  | -2.50 | -1.97 |
| October   | 2.81 | 1.09  | 0.43  | -0.88 | -0.87 |

### Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.
- Relationships between the 90-day Sum06 accumulation periods and soil moisture are difficult to assess because ozone exposure was relatively similar in all five years. However, soil moisture levels associated with the Sum06 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. Soil moisture levels during the year with the highest Sum06 value, 1999, show three months of mild to moderate levels of drought. There were only two months of drought in the remaining four years. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations. In the highest ozone years, 1998 and 1999, soil moisture conditions were at mild and moderate drought levels for five months and one month, respectively. In the three years when ozone exposures were lower, soil moisture conditions were favorable for the uptake of ozone with only one month of mild drought in 1997.

The risk of foliar ozone injury to plants at Stones River National Battlefield is high. While the levels of ozone exposure consistently create the potential for injury, dry soil

conditions may reduce the likelihood of injury developing in the highest exposure years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1995, 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, American sycamore, black cherry and American elder.